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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 402

PERMANENT COMMISSION OF AERONAUTICAL STUDIES

REPORT NO. 4

Supplement to "Bulletin de la Chambre Syndicale des Industries Aéronautiques
September-December, 1926, Volume IV, Nos. 5-6

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PERMANENT COMMISSION OF AERONAUTICAL STUDIES.*

REPORT NO. 4.

While the Permanent Commission of Aeronautical Studies was holding its meeting on March 25, 1925, Mr. Chollat read a report on the methods, applying calculation to the determination of the mechanical resistance of airplanes. The report dealt, furthermore, with the methods of verification and the static tests by which said calculations are checked.

The question was considered important enough to account for the creation of a subcommission consisting of Mr. Sabatier, president, and the following members: Messrs. Breguet, Blanchet, Camerman, Caquot, Chauviere, Chollat, Delage, Delanghe, Duval, de L'Escaille, Gourdou, Grimault, Lepere, Lesage, Letang, Marchis, Toussaint, Volmerange.

The first meeting of the subcommission was held on May 13, 1925. It was then decided to entrust a group of four members with working out a report on the subject considered.

This group, consisting of Messrs. Chollat, Gourdou, Grimault, Lepere, assisted by Mr. Suffrin, met on January 12, 22, 28, and on February 2 and 15, at the "Service Technique de l'Aéronautique. During the meeting of the subcommission on February 12, the group gave an account of the progress of its

*Supplement to "Bulletin de la Chambre Syndicale des Industries Aéronautiques," September-December, 1926, Volume IV, Nos. 5-6.

work. Its conclusions, approved by the subcommission, are summarized in the present report.

Progress in aviation is closely connected with increase of safety in all lines, but chiefly with safety of construction. Recent accidents, which were the result of structural failure, in flight, revealed the necessity of a closer examination of the conditions under which the resistance of airplane structures may be calculated.

The general method which was adopted to this end comprises the following stages:

1. Determination of the main conditions entailing overload and examination of the existing theoretical and experimental data.
2. Reduction of the general conditions of calculation to some simple cases.
3. Determination of the load factors* to be adopted in each of these cases.
4. Methods of control, known as static tests.

* See in Appendix, definition of the expression "load factor."

I. Determination of the Main Conditions Entailing Overload and Examination of the Existing Theoretical and Experimental Data.

Overload can be the result of either a maneuver of the pilot or an atmospheric disturbance.

Experiments carried out in different countries made it possible to measure certain components of the acceleration in most maneuvers. Accounts of some results may be found in N.A.C.A. Technical Report No. 203, and in Bulletin No. 30, of the "Service Technique de l'Aéronautique," these documents being the main data upon which the following considerations are based. Maximum normal accelerations of 7 g were obtained at the wing chord of pursuit type airplanes while pulling out of a dive. Therefore, the calculation of the airplane will be based on this figure. Lower accelerations are produced by other maneuvers. Evolutions entailing unequal stresses produce lower normal accelerations although they may result in very important local stresses. The value of the accelerations caused by atmospheric disturbances lies around 3.5 g for airplanes which do not perform stunts. (See table from Technical Bulletin No. 30, of the "Service Technique de l'Aéronautique.")

The maximum accelerations obtained are only relative maxima. More sudden maneuvers can be carried out. Theoretically,

much higher accelerations can be obtained.

Conditions in flight will be first considered; it is understood that in all cases the considerations apply to the whole of the airplane including wings, fuselage and tail planes, owing to the fact that the general structure must be homogeneous and that the forces acting upon the airplane must be in equilibrium.

The maximum loads to be imposed and consequently the dimensions of each part will be deducted in each case of flight for every part of the airplane out of the examination of the equilibrium.

Landing loads and unequal loads during the maneuvers will be considered later on.

II. Reduction of the General Conditions of Calculation to Some Simple Cases.

There exists a theoretical trajectory of the airplane along a vertical plane, where most of the cases of symmetrical overload are encountered.

The definition of this trajectory is given as follows: The airplane dives along a slope determined by the maximum limiting speed and is progressively pulled out of the dive, reaching at a certain moment its maximum acceleration (limited either psychologically or physiologically). It is assumed that the craft loses no speed during this maneuver, which is carried out

in a fraction of a second. It is also assumed that the airplane maintains henceforth a constant normal acceleration while the angle of attack increases up to a value corresponding to C_z maximum.

All the overloads corresponding to the different conditions of flight can be defined by means of the theoretical trajectory, it being understood that the normal acceleration is always maintained around its previously determined maximum value.

This hypothesis includes all the cases in which the airplane is pulled out of dives at maximum accelerations and variable angles of attack and speeds.

The theoretical trajectory comprises three particularly characteristic conditions of flight:

1. Nose dive (3d case of the C.I.N.A.).
2. Passing to the angle of attack of normal flight with maximum overload (2d case of the C.I.N.A.).
3. Pulling out of dives at different angles of attack and equal overloads (this case includes the 1st case of the C.I.N.A.).

The following documents are particularly required for these calculations:

1. The polar curve of the wing only and the polar curve of the complete airplane, thereby taking into consideration the parts which might be possibly omitted on the model.

2. The law of pressure distribution on the employed wing (experiments or calculations).
3. The curves of equilibrium and stability (model tests or calculations).
4. Law of propeller braking.

The application of theoretical calculations must be always based upon practical results of wind tunnel tests or tests in flight. Therefore, aerodynamical studies of currently used wing sections were continually referred to. Consequently, the suggested methods can be applied to normal cases only. Whenever it is proved by corrections based upon wind tunnel tests or tests in actual flight, that the particular case considered differs from the general case, the rules will have to be modified according to the results of the experiment.

Nose Dive (Case No. 3, of the C.I.N.A.).

It is admitted that the nose dive corresponds to a descent along the trajectory of maximum limiting speed, the engine being throttled down, switched off and rotating only under the action of the wind-driven propeller.

The dive is performed with a very small c_z, corresponding to the minimum total resultant. Then the theoretical limiting speed of the dive can be calculated out of these data.

The propeller resistance is expressed by the following formula:

$$R = K \frac{a}{g} V^2 D^2$$

where a is the specific weight of the air, g the acceleration due to gravity, V the limiting speed, D the diameter of the propeller calculated according to the M.K.S. system.

No satisfactory data are available at the present time for the accurate determination of the value of K. The present state of the question is outlined in an annexed report. However, there is an urgent demand for experiments capable of supplying more complete numerical data. There is no apparent use of considering the case when the engine is completely stopped, from a general point of view, as the propeller is driven in most cases by the pressure of the air.

The limiting speed obtained by this calculation is never practically realized owing to the fact that the descent takes place along a slope which is inferior to the slope of the maximum limiting speed. Also it is not generally sufficiently extended. Under these conditions the loads actually imposed are inferior to the anticipated maximum.

Moreover, once the permanent conditions of nose dive established, the adopted load factors will be actually the factors of safety which may be consequently rather small.

With reference to the limiting nose dive, it is evidenced by concrete examples that, when the passive resistances are taken into consideration, a considerable moment is exerted upon the wing, at least upon certain sections. This moment is equilibrated by the moment of the tail group, which exerts a consid-

erable stress upon the fuselage. On the other hand, this moment may deflect the wing by torsion and due attention must be paid to the danger of using such wing sections.

Of all performances in flight, the dive imposes as a general rule, the highest bending stress upon the fuselage and the maximum torsion upon the wing. Under these conditions:

1. The highest load is imposed in the direction of the lift on the rear spar and the corresponding bracing;
2. The highest load is imposed in the direction opposite to the direction of the lift on the front spar and the corresponding bracing.

Attention must also be paid to the fact that even slight oscillations produced around the vertical trajectory during a dive may result in additional loads on the front part of the wing during each phase of oscillation corresponding to a negative lift.

Determination of the Elements of Calculation

It is assumed that the airplane descends along the trajectory of maximum limiting speed, the limiting speed being determined by taking into consideration the weight of the airplane, its aerodynamical resistance and the propeller braking. It is admitted that the density of the air is that corresponding to the altitude $Z = 0$ in standard atmosphere, the most unfavorable conditions being thus obtained. At the same time the air-

plane must be in equilibrium or its central moment equal to zero, this position being best achieved by a convenient setting of the elevator. This setting entails a variation of the lift of the tail group and consequently of the airplane.

The position of equilibrium of the airplane and stabilizer is found by successive approximations.

The change of the aerodynamical resistance is usually negligible as it takes place near a minimum. Accordingly, the limiting speed is not modified as, otherwise, the preceding calculations ought to be started anew.

The system of forces in equilibrium, which act upon the airplane, being thus determined, it is assumed for the resistance calculation that each of these forces is multiplied by the load factor.

Flight at Maximum Speed (Case No. 2, of the C.I.N.A.)

The case of flight at maximum speed is that of normal flight. The calculation of the entailed stresses is therefore particularly important.

It is also interesting owing to the fact that, under present conditions, it corresponds to a position of the C.P. intermediary between the extreme positions admitted for the other two cases.

Although this position is obviously more forward than in the case of a nose dive, it can lead to higher stresses upon the rear spar owing to the imposed load factor. These conditions

must be taken into consideration when choosing the wing section. The determination of the load factor is considered further on.

Determination of the Elements of Calculation.

The angle of attack corresponding to this case of calculation must be first determined. To this end uniform conditions of horizontal flight are assumed, the airplane flying at the maximum speed obtained when using the nominal power of the engine at the altitude $Z = 0$ of standard atmosphere.

At the same time the airplane must be in equilibrium or the central moment equal to zero, which is only obtained by an appropriate setting of the elevator taking into consideration the wash produced by the wing. The setting entails a variation of the lift of the tail group and consequently of the airplane.

The position of equilibrium of the airplane and stabilizer is found by successive approximations.

The system of forces in equilibrium which act upon the airplane, being thus determined, the resistance calculations are based on the assumption that each of these forces is multiplied by the load factor, in which case the airplane is supposed to travêl along a curved trajectory at such speed that the total normal accelerations be equal to $n\ g$. However, the propeller thrust will be multiplied by a lower factor, its value being practically limited. Besides, there is a uniform variation of the motion along the above-mentioned trajectory, the parasite

resistance being thus a sum of the propeller thrust and of the tangential inertial force.

Flight with C.P. in Extreme Front Position
(Case No. 1, of the C.I.N.A.).

This case corresponds to the end of a pull-out of a nose dive along the previously determined theoretical trajectory. On the other hand, this position of the C.P. is reached when the value of c_z is close to maximum. This coincidence accounts for the fact that the C.I.N.A. selected this particular case of calculation although it represents a rarely attained limit.

The calculations referring to this case are established with a view to determining the maximum stresses entailed in the front part (spar and bracing) of the wings.

In the case of a monoplane wing the admitted position will be that in which the intersection of the main chord and the line of the resultant air force is nearest to the leading edge. In the case of multiplane wings the determination of the position to be adopted is necessarily more arbitrary and will be considered further on.

Determination of the Elements of Calculation.

The airplane is assumed to be flying horizontally at an angle of attack corresponding to the adopted position of the C.P.

In order to maintain the airplane in equilibrium the moment of the system of forces must be nought with regard to the center

of gravity. This is only obtained by an appropriate setting of the elevator, taking into consideration the wash of the wing. The setting entails a variation of the lift of the tail group and consequently of the airplane.

The position of the airplane and elevator which corresponds to a state of equilibrium is found by successive approximations.

It may be admitted that this case of flight does not correspond to uniform conditions but only occurs during a maneuver entailing a negative acceleration. The propeller thrust which forms a component of the acceleration is not taken into consideration.

Conclusions.

It results from what has been said above, that the three cases pointed out by the C.I.N.A. are necessary and sufficient for ordinary changes of position of an airplane. However, for airplanes designed to perform stunts, such as pursuit airplanes, it is advisable to consider a fourth case, which is that of inverted flight, particularly when pulling out of a nose dive into the inverted flight position.

Under normal conditions this maneuver is not advisable, but it may become necessary under certain circumstances, wherefore it would be wrong to neglect it *a priori*.

The study of the polar curves with negative lift would provide for useful indications regarding the values of c_z in the

neighborhood of the lift equal to zero. Thus, useful information would be supplied on this case.

III. Load Factors.

As regards the following, it is referred to the general technical conditions of the S.T.Aé., dated September 16, 1925. The reprinted table of the C.I.N.A. covers civil airplanes, while the table of the S.T.Aé. refers to military airplanes.

Table of Load Factors Applied to the Airplane Proper.

Purpose of the craft		1st case: Total weight of the airplane. below 1000 kg (2200 lb.)	from 1000 to 5000 kg (11000 lb.)	above 5000 kg (11000 lb.)	2d case	3d case
C.I.N.A.	Civil -					
	Normal	7	7 to 5	5	3/4 of the preceding factors	1.5
	Special record	5	5 to 4	4		1.2
	Stunting	9	9 to 7	7		2.5
S.T.Aé.	Civil -					
	Normal	8	8 to 6	6		2.0
	Special record	6	6	6		1.5
	Stunting	12	12 to 9	6		3.0

Table (Cont.)

	Purpose of the craft	1st case: Total weight of the airplane below 1000 kg (2200 lb.)	1st case: Total weight of the airplane from 1000 to 5000 kg (11000 lb.)	1st case: Total weight of the airplane above 5000 kg (11000 lb.)	2d case	3d case
S.T.Ae.	Military –					
	Bombing heavy load carrier training; sanitary	8	8 to 6	6		2
	Multi-seater; T.O.E. day bomber..........	9	9 to 7	7		3
	Pursuit; reconnaissance; experimental ..	13	13 to 10	10		4

Nose Dive (3d Case of the C.I.N.A.)

It has already been pointed out that in this case the load factor is actually the factor of safety. The Commission considers that the factors anticipated in the general technical conditions must be verified in order to avoid excessive loads. The Commission believes that the factor 4 is too high even for pursuit airplanes. It appears that the factor 2 might be sufficient.

With regard to airplanes, which, unlike those of the pursuit type, are not designed to dive at the limiting speed, it is necessary to provide for proportionally lower load factors. As for

the heavy bombers and transport airplanes, it seems that the factor 1.5, adopted by the C.I.N.A., may be temporarily used as a basis until more complete information is supplied. An intermediary factor might be applied to other airplane types.

Flight with C.P. in Extreme Front Position
(1st case of the C.I.N.A.).

The determination of the load factors to be adopted in this case is empirical. The following well-known formula was previously used:

$$K \frac{S}{T_o} \left(\frac{V_o}{100}\right)^3$$

(S, wing area in square meters; T_o, power in horsepower; V_o, speed in kilometers per hour).

This formula has the inconvenience of introducing as a factor of third power the maximum speed, which is only determined after testing the airplane in flight. Under these conditions, it may happen that an airplane having successfully passed the static tests according to the anticipated speed, will not satisfy the resistance specifications if the actual speed exceeds the anticipated speed.

On the other hand, the formula comprises an arbitrary coefficient K, the different values of which were practically confirmed.

In view of the results previously obtained, the C.I.N.A. a and the S.T.Ae. preferred to determine a priori for each cate-

gory of airplanes a load factor independent of the speed and based solely on the weight of the airplane which characterizes practically the rapidity of maneuver and consequently, the intensity of the maximum accelerations.

The load factors for different categories of airplanes were indicated in a table, the weight being taken into consideration.

Flight at Maximum Speed.

The value of the load factor to be adopted in this case was fixed by the C.I.N.A. and the S.T.Aé. at 3/4 of the value applied to the case of flight with C.P. in extreme front position:

This arrangement is logical in principle, as the maximum admitted acceleration could not be reached for the value c_{zh} corresponding to the considered case of horizontal flight, if it is assumed that the airplane has reached and maintained its limiting diving speed. In fact, owing to previous hypothesis, the normal acceleration is proportional to c_z.

Referring to note of M. Gourdou, it will be found that the ratio between the value c_{zh} of horizontal flight and the minimum value c_{zr} required for obtaining the acceleration n g, can be considered not only as a function of n, but also of the weight, the power and speed in horizontal flight.

However, it was admitted that past the point of the theoretical trajectory, where the airplane reaches the lift correspond-

ing to c_{zr}, the normal acceleration is constantly maintained equal to n g, owing to a simultaneous variation of c_z and V, wherefore the lift remains constant. Consequently, it may be admitted with a sufficient approximation, that the load factor of horizontal flight can be compared to either of the load factors corresponding to c_{zr}, or to the extreme front position of the C.P.

With the brake factor admitted in the note, it is probable that the ratio 0.75 refers to the case of $n = 6$, applied to ordinary reconnaissance airplanes. For other values of n and other types of airplanes, it is advisable to verify the value of this factor in each case.

Resolutions

Although the Commission has not yet completed the examination of all the questions relating to static tests, it has already formed conclusions of sufficient importance to adopt at once the following resolutions without awaiting the publication of the general report:

The Permanent Commission of Aeronautical Studies, considering that progress in aviation is closely connected with increase of safety in all lines, but chiefly with safety of construction,

Considering that several accidents resulting from ruptures in flight were partly due to deficient knowledge of the instanta-

neous loads and to imperfect methods of calculation,

Considering finally that such accidents will be henceforth best avoided by an exact knowledge of their causes, adopts the following resolutions:

1. That, as far as possible, a methodical analysis of the main causes to which recent accidents were due, be worked out and forwarded to the Commission;

2. That urgent systematic tests in flight be carried on with recording instruments in order to obtain accurate determination of the maximum stresses exerted upon airplanes and the conditions under which they are produced;

3. That the coefficient to be adopted for braking the propeller in nose dive be determined by laboratory tests, for a propeller rotating loose, a fixed propeller and particularly for a propeller braked by the engine;

4. That measurements of local and total pressures on wings and tail planes be carried on at the laboratory and in flight for all possible angles of stunt flight, as well as the study of the influence exerted by the interaction upon the distribution of the lift and upon the position of the C.P. in multiplanes;

5. That it would be particularly useful for commercial airplanes to carry on the studies regarding the wind velocity and its variations, these studies having already given interesting results.

Appendix

Definition of the Load Factor

Attention is called to the distinction to be made between the "factor of safety" and the "load factor."

When calculating the characteristics of a structural part the loads supported by this part under most unfavorable conditions are first evaluated and then multiplied by the factor of safety. Loads are thus obtained which must be supported by this part under tests, before giving way.

For complex framework, such as airplane structures, it is impossible to consider the maximum stresses exerted upon each part considered separately, and the study is therefore reduced to a certain number of typical cases.

Usually such cases do not correspond to the most unfavorable conditions which certain parts of the structure may be placed in. Therefore, in order to maintain the same degree of relative similarity, the imposed loads must be multiplied by a higher factor than the factor of safety referred to above, this higher factor being termed load factor.

Therefore the value of the load factor could not be equal to that of the factor of safety unless the particular case referred to be effectively the most unfavorable which might be considered.

Table of Accelerations Measured in Flight During Different Maneuvers by Means of The Huguenard, Magnan, and Planiol Accelerometer.

Performed maneuver	Date of test	Airplane	Pilot	Total value of normal acceleration at the wings	Maximum angle of control stick to the 0 position
Loops	6-11-25	Gourdou 180 HP.	Christiany	5.5 g	+ 18°
"	"	"	"	5.7 g	+ 13.5°
"	6-16-25	"	Devillers	4.85 g	+ 5.8
"	"	"	"	4.82 g	+ 6.8°
Barrel rolls	"	"	"	4.91 g	+ 14°
"	"	"	"	5.27 g	+ 15.5°
Inverted flight	6-11-25	"	Christiany	3.9 g	+ 6.5°
"	"	"	"	4.4 g	+ 2.5°
Vertical bank	6-16-25	"	Devillers	5.04 g	+ 1.6°
Pulling out of a dive	6-11-25	"	Christiany	4.2 g	+ 2.1°
"	"	"	"	4.3 g	+ 9.5°
"	6-16-25	"	Devillers	5.59 g	+ 3°
"	"	"	"	6.46 g	+ 1.8°
Spin	"	"	"	0.6 g to 1.3 g	+ 20.5°
At the end of the spin	"	"	"	2.3 g	-
Sudden landing	"	"	"	5.2 g	-
Normal landing	8- 2-25	Caudron 127	Becheler	4.3 g	-
Smooth landing	"	"	"	3.1 g	-
Alighting	10-30-25	Farman seaplane	Lt. Paris	0.1 g	-

Table of Accelerations Measured in Flight During Different Maneuvers by Means of The Huguenard, Magnan, and Planiol Accelerometer (Cont.)*

Performed maneuver	Date of test	Airplane	Pilot	Total value of normal acceleration at the wings	Maximum angle of control stick to the 0 position
Flight in rising sea wind of 9 m/sec, power off, (in the region of Vauville)	8- 2-25	Caudron 127	Becheler	1.13 g	-
Flight in rough air aft of the rising wind zone (in the region of Vauville)	"	"	"	1.25 g	-
b) between Barcelona and Toulouse	9-26-25	Farman limousine	Hamm	2.1 g	
c) in the region of Bizerte	10-20-25	Farman seaplane	Lt. Paris	1.3 g	-

* From Technical Bulletin No. 30, of the "Service Technique de l'Aeronautique," p.47.

Translation by W. L. Koporinde, Paris Office,
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